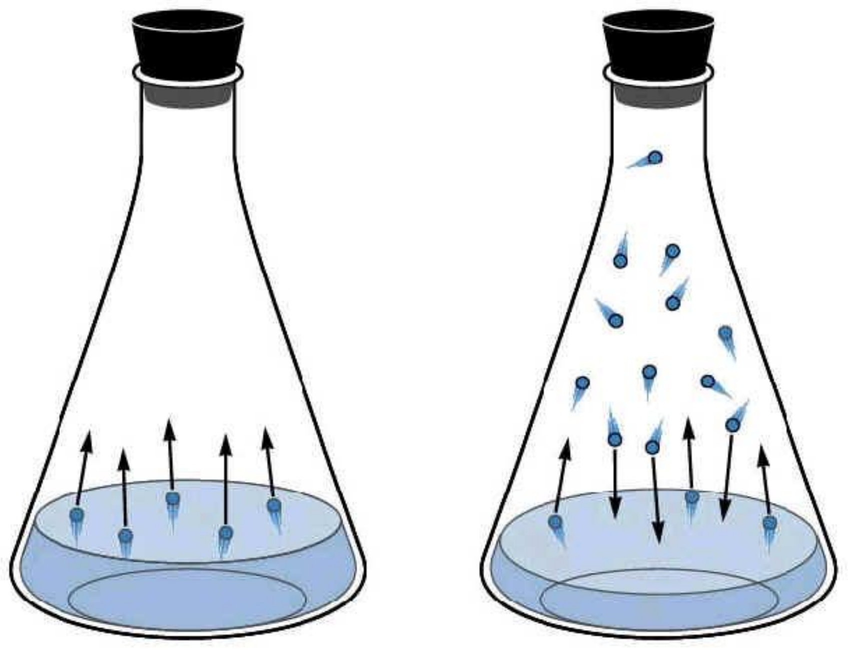
Colligative Properties

Colligative Properties

- Properties of solutions that depend the ratio of the number of solute particles to the number of solvent molecules in a solution
- Depend on the number, not the identity, of the solute particles in an ideal solution
- Four different properties
  - Vapor pressure
  - Boiling point elevation
  - Freezing point depression
  - Osmotic pressure

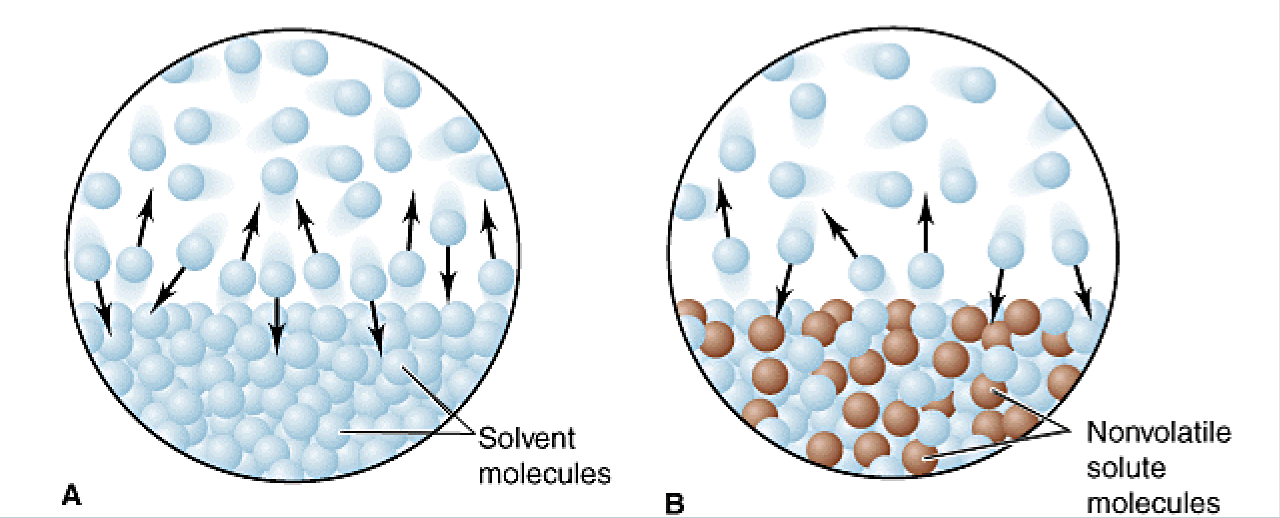
Vapor Pressure

- The pressure above the liquid from the molecules of the liquid in the gas phase
- Intermolecular forces & vapor pressure
  - Lower intermolecular forces in liquid = high vapor pressure
  - High intermolecular forces in liquid = low vapor pressure
- Increases with temperature
  - More kinetic energy to overcome intermolecular forces



Lowering Vapor Pressure

- Volatile liquid = high vapor pressure
  - More likely to become a gas
- Nonvolatile liquid = low vapor pressure
- Nonvolatile solute lowers vapor pressure of solvent
  - Decreases the escaping tendency of solvent molecules



Rauolt's Law

- States that the vapor pressure of a solution is directly proportional to the mole fraction of the solvent present

$$P_{sol'n} = X_{solvent} P°_{solvent}$$

  - $P_{sol'n}$ = observed vapor pressure of solution
  - $X_{solvent}$ = mole fraction of solvent
  - $P°_{solvent}$ = vapor pressure of the pure solvent
- Nonideal solutions
  - Occurs when more than one solute

$$P_{total} = X_A P°_A + X_B P°_B$$

Raoult's Law Example

- Calculate the expected vapor pressure at 25°C for a solution prepared by dissolving 158.0 g of common table sugar (sucrose, molar mass = 342.3 g/mol) in 643.5 mL of water. At 25°C, the density of water is 0.9971 g/mL and the vapor pressure is 23.76 torr.

$$n_{sucrose} = 158.0\ g\ x\ \frac{1\ mol}{342.3\ g} = 0.4616\ mol$$

$$n_{water} = 643.5\ mL\ x\ \frac{0.9971\ g}{1\ mL}\ x\ \frac{1\ mol}{18.02\ g} = 35.63\ mol$$

Raoult's Law Example

$$X_{water} = \frac{n_{water}}{n_{sucrose} + n_{water}} = \frac{35.63\ mol}{0.4616\ mol + 35.63\ mol}$$
$$= 0.9873$$

$$P_{sol'n} = X_{water} P°_{water} = (0.9873)(23.76\ torr)$$
$$= 23.46\ torr$$

Boiling Point Elevation

- Normal boiling point—the point where the vapor pressure of liquid equals 1 atmosphere
- Nonvolatile solute elevates boiling point of solution
  - Vapor pressure lowered with a nonvolatile solute
  - More temperature needed to overcome the intramolecular forces

$$\Delta T_b = K_b m$$

  - K_b = molal boiling point elevation constant of solvent
  - m = molality of solute in solvent

Boiling Point Elevation Example

- Automotive antifreeze consists of ethylene glycol ($C_2H_6O_2$), a nonvolatile nonelectrolyte. Calculate the boiling point of a 25.0 mass percent solution of ethylene glycol in water.
  - Assume 1000 g so there are 250 g of ethylene glycol and 750 g of water

$$250\ g\ C_2H_6O_2\ x\ \frac{1\ mol}{62.1\ g} = 4.026\ mol\ C_2H_6O_2$$

$$750\ g\ water\ x\ \frac{1\ kg}{1000g} = 0.750\ kg$$

Boiling Point Elevation Example

$$m = \frac{moles\ of\ C_2H_6O_2}{kg\ of\ water} = \frac{4.026\ mol}{0.750\ kg} = 5.37\ m$$

$$\Delta T_b = K_b m = \left(0.51 \frac{°C}{m}\right)(5.37\ m) = 2.7°C$$

$$Boiling\ point = T_b + \Delta T_b = 100.0°C + 2.7°C = 102.7°C$$

Boiling Point Elevation Example #2

- A solution was prepared by dissolving 18.00 g glucose in 150.0 g water. The resulting solution was found to have a boiling point of 100.34°C.Calculate the molar mass of glucose. Glucose is a molecular solid that is present as individual molecules in solution.

$T_b = 100.0°C$

$$\Delta T = 100.34°\text{C} - 100.0°\text{C} = 0.34°\text{C}$$

$$\Delta T = K_b m \rightarrow m = \frac{\Delta T}{K_b}$$

Boiling Point Elevation Example #2

$$m = \frac{\Delta T}{K_b} = \frac{0.34℃}{0.51\,\frac{℃ \cdot kg}{mol}} = 0.67\,\frac{mol}{kg}$$

$$m_{solute} = \frac{mol\ of\ solute}{kg\ of\ solvent} \rightarrow n_{solute} = (m_{solute})(kg\ of\ solvent)$$

$$n_{solute} = \left(0.67\,\frac{mol}{kg}\right)(0.1500\ kg) = 0.10\ mol$$

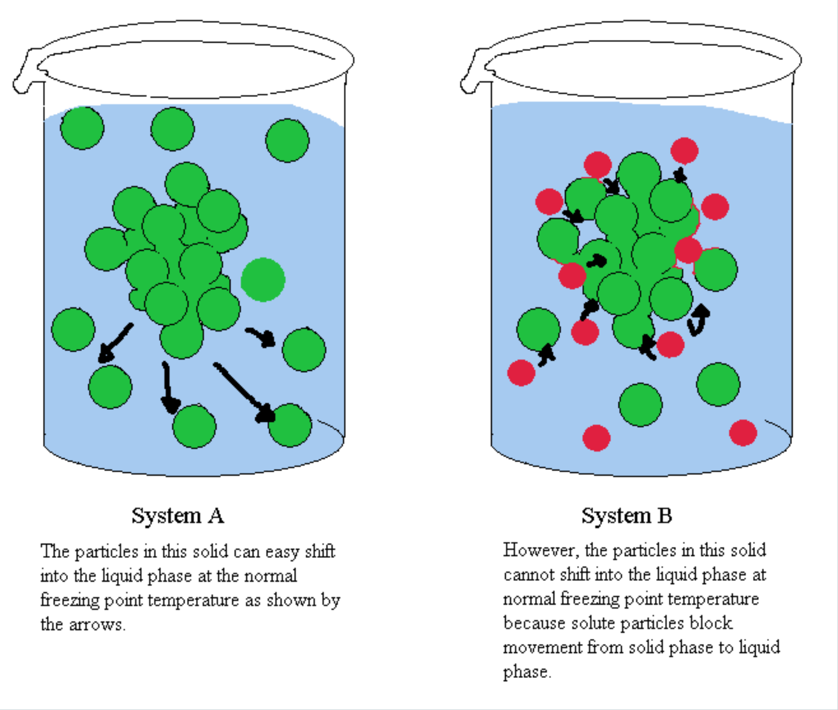
$$MM = \frac{mass}{mol} = \frac{18.00\ g}{0.10\ mol} = 180.0\ g/mol$$

Freezing Point Depression

- A nonvolatile solute decreases the freezing point of a solvent

$$\Delta T_f = K_f m$$

  - K_f = molal freezing point depression constant of solvent
  - m = molality of the solute in solvent



Freezing Point Depression Example

- Automotive antifreeze consists of ethylene glycol ($C_2H_6O_2$), a nonvolatile nonelectrolyte. Calculate the freezing point of a 25.0 mass percent solution of ethylene glycol in water.

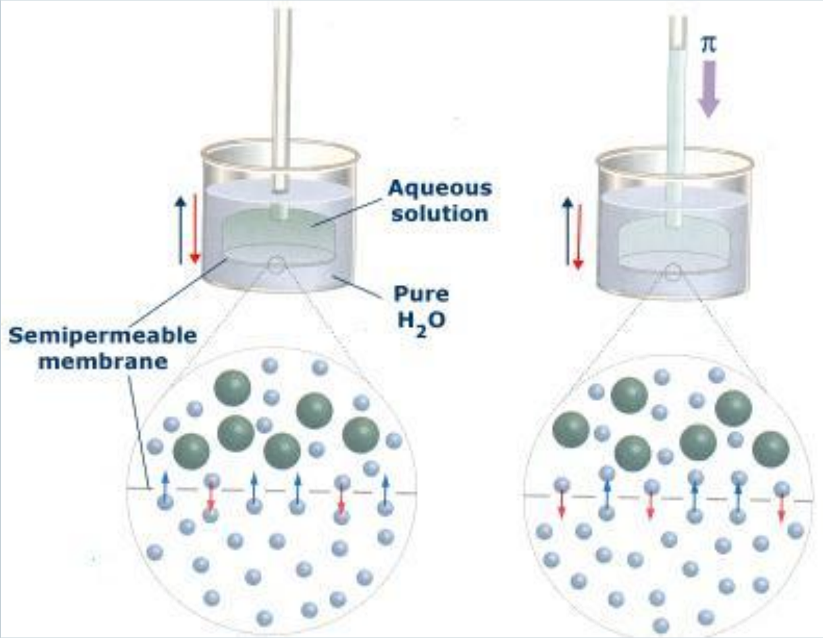
  $n_{ethylene\ glycol} = 4.026$ mol
  mass of water = 0.750 kg

$$m = \frac{moles\ of\ ethylene\ glycol}{mass\ of\ water} = \frac{4.026\ mol}{0.750\ kg} = 5.37\ m$$

$$\Delta T_f = K_f m = \left(1.86 \frac{°\mathrm{C}}{m}\right)(5.37\ m) = 10.0°\mathrm{C}$$

$$Freezing\ point = T_f - \Delta T_f = 0.0°\mathrm{C} - 10.0°\mathrm{C} = -10.0°\mathrm{C}$$

Osmotic Pressure



- Osmosis—the flow of a pure solvent into a solution through a semipermeable membrane
- Osmotic pressure—the pressure that must be applied to a solution to stop osmosis

$$\pi = MRT$$

  - π = osmotic pressure (in atm)
  - M = molarity of solvent
  - R = Gas law constant (0.0821 Latm/Kmol)
  - T = temperature (K)

Osmotic Pressure Example

- The average osmotic pressure of blood is 7.7 atm at 25°C. What concentration of glucose will be isotonic with blood?
  - Isotonic means equal movement of particles on both sides of semipermeable membrane

$$\pi = MRT \rightarrow M = \frac{\pi}{RT} = \frac{7.7\ atm}{\left(0.0821\ \frac{L \cdot atm}{K \cdot mol}\right)(298\ K)}$$

$$= 0.31\ M$$

Colligative Properties of Electrolyte Solutions

- Colligative properties depend on total concentration of solute particles
  - Sometimes number of solute particles is greater than one (ionic solutions)
- van't Hoff factor (i)—expression relating the moles of solute dissolved and the moles of particles in solution

$$i = \frac{moles\ of\ particles\ in\ solution}{moles\ of\ solute\ dissolved}$$

  - Expected value of i—calculate by noting number of ions per formula unit
    - Not always correct assumption

Colligative Properties of Electrolyte Solutions

- Colligative Properties Formulas of Electrolytes

$$\Delta T_b = iK_b m \text{ or } \Delta T_f = iK_f m$$

$$\pi = iMRT$$

Colligative Properties of Electrolytes Solution Example

- The observed osmotic pressure for a 0.10 M solution of $Fe(NH_4)_2(SO_4)_2$ at 25°C is 10.8 atm. Compare the expected and experimental values for i.
  - Reaction equation:

    $$Fe(NH_4)_2(SO_4)_2 \rightarrow Fe^{2+} + 2\ NH_4^+ + 2\ SO_4^{2-}$$

    - Creates 5 ions so $i = 5$

$$\pi = iMRT \rightarrow i = \frac{\pi}{MRT}$$

$$= \frac{10.8\ atm}{\left(0.10\frac{mol}{L}\right)\left(0.0821\frac{L \cdot atm}{K \cdot mol}\right)(298\ K)} = 4.4$$